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Serial No.	:	**To Be Assigned**
Filing Date	:	**Herewith**
For	:	**Wireless Sensor Power Supply and Signal Read-Out**

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U.S. PROVISIONAL APPLICATION REQUEST TRANSMITTAL

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Enclosed herewith please find the following:

1. 37 sheets of Specification
2. Returned Receipt Postcard.

Please charge the deposit account of **Fay Kaplun & Marcin, LLP No. 50-1492** in the amount of **$160.00**. The Commissioner is hereby authorized to charge the payment of any additional fees associated with this communication or arising during the pendency of this application to the Deposit Account of Fay Kaplun & Marcin, LLP. A copy of this Transmittal is submitted for this purpose.

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[40124/03601]

U.S. PROVISIONAL PATENT APPLICATION

For

WIRELESS SENSOR POWER SUPPLY AND SIGNAL READ-OUT

Inventor(s):
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Total Pages (including title page and specification): **37**

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Name: Oleg F. Kaplun, Reg. No. 45.559

Signature

NCTE (NCTEngineering GmbH) is a sensor engineering and manufacturing company in Ottobrunn near Munich, founded in 2003. NCTE stands for Non Contact Torque Engineering.

The engineering team from NCTE has supported the motor sport market for the last 8 years in providing F1 teams and selected industries with Non-Contact-Torque sensors.

NCTE is using its patented "PCME" sensing technology, applied to an already existing input / output shaft, to measure absolute torque (and other physical parameters) with a signal bandwidth of 10 kHz and a repeatability of 0.01%. The systems total electrical current consumption is below 8 mA.

Features and performances of a NCTE torque sensor for motor sport

Parameter	Conditions	min	Typ	max	Units
Torque Measurement Range	Full Scale Measurement Range	+/- 1		+/- 7000	Nm
Signal Bandwidth	Customer Definable	100		>10,000	Hz
Signal Resolution (analog output signal)	Is a function of signal bandwidth	Equivalent to 12		Equivalent to 16	Bit
Measurement Repeatability			0.01		%
Allowable Shaft Rotation		Stationary		100,000	rpm
Electrical Supply Voltage	Single Supply Voltage		5.00		V
Electrical Supply Current	One measurement channel with analog output Voltage	4.8	6	8	mA
Operating Temp Range	Primary Sensor	-50		+210	^{0}C
Operating Temp Range	Secondary Sensor	-50		+125	^{0}C

The primary sensor system is resistive to water, gearbox oil, and non-corrosive / non-Ferro-magnetic materials. This technology can be applied to solid or hollow Ferro magnetic shafts as they are used in motor sport applications (examples: 50NiCr13, X4CrNi13-4, 14NiCr13, S155, FV520b, ..).

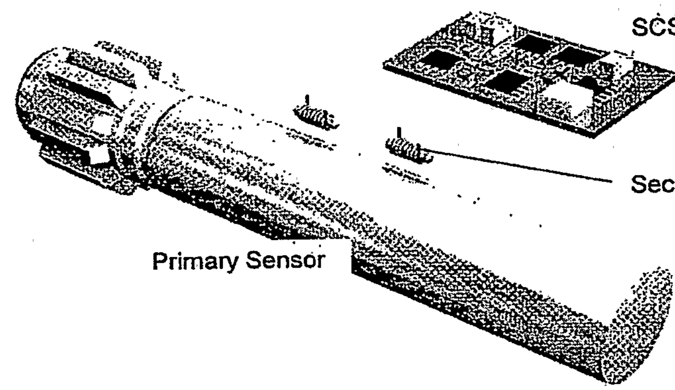
No mechanical changes are necessary on the input / output shaft (primary sensor), nor will be anything attached or glued to the shaft in any way. The input / output shaft keeps all of its mechanical properties when the NCTE technology will be applied.

In a typical motor sport program NCTE requires around 20 working days to apply its torque sensing technology to a new custom application. The turn-around supply time for a system that has been already developed is typically less then three days (re-ordering of processed Primary Sensors).

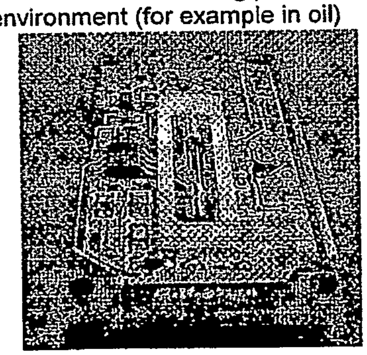
The three main modules of an NCTE sensor

A NCTE sensing system consists of three main building blocks (or modules): the **Primary Sensor**, the **Secondary Sensor**, and the **SCSP** (Signal Conditioning & Signal Processing) electronics.

The **Primary Sensor** is a magnetically encoded region at the power transmitting shaft. The encoding process is performed "one" time only (before the final assembly of the power transmitting shaft) and is permanent. The power transmitting shaft is also called Sensor Host (or **SH**) and has to be manufactured from Ferro magnetic material. In general, industrial steels that include around 2% to 6% Ni will be a good basis for the NCT sensor system. The Primary Sensor converts the changes of the physical stresses applied to the SH into changes of the magnetic signature that can be detected at the surface of the magnetically encoded region. The SH can be solid or hollow.



The **Secondary Sensor** is a number of Magnetic Field Sensor (**MFS**) devices that are placed nearest to the magnetically encoded region of the SH. However, the MFS devices do not need to touch the SH so that the SH can rotate freely in any direction. The Secondary Sensor converts changes of the magnetic field (caused by the Primary Sensor) into electrical information. NCTE is using passive MFS devices (coils) as they can be used in harsh environment (for example in oil) and operates in a very wide temperature range.

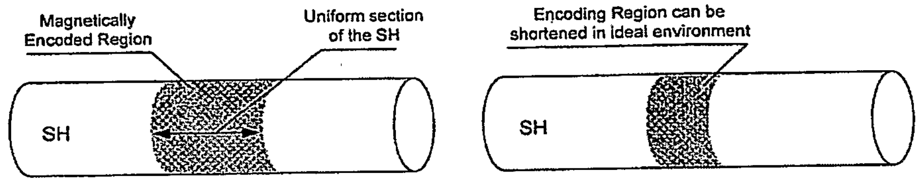


The **SCSP** (Signal Conditioning & Signal Processing) electronics drives the MFS coils and provides the user with a standard format signal output. The SCSP electronics will be connected through a twisted pair cable (2 wires only) to the MFS coils and can be placed up to 2 Meters away from the MFS coils. The SCSP electronics from NCTE is custom designed and has a typical current consumption of 5 mA.

Primary Sensor Design: Magnetically Encoded Region

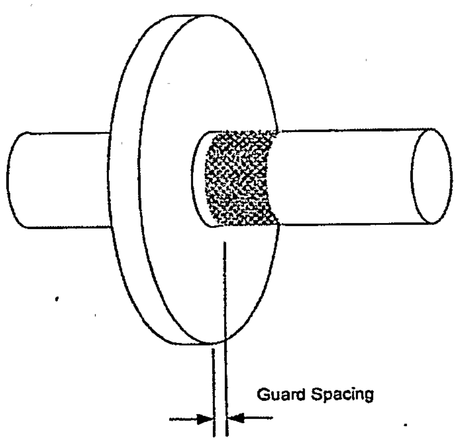
The magnetic encoding process from NCTE is relative flexible and can be applied to shafts (SH) with a diameter ranging from less than 2 mm to greater than 200 mm. The SH can be hollow or solid as the signal can be detected equally on the outside and on the inside of a hollow shaft.

In a sensor system where the SH has to be able to rotated the Encoding Region can be placed anywhere along the SH as long as the chosen location is of uniform (round) shape and does not change in diameter for a few millimeters. The axial length of the Encoding Region depends on the: SH diameter, the environment, and the expected system performances. In general a longer Encoding Region provides better results (improved signal-to-noise ration) then a shorter Encoding Region.



For example, for a SH with a diameter of less than 10 mm the magnetic Encoding Region should not be longer than 25 mm and can be as short as 10 mm (always assuming under ideal circumstances.

For a shaft of 30 mm diameter the magnetic Encoding Region can be as long as 60 mm. When the SH diameter increases further it becomes difficult to produce fully functional Encoding Regions that are very short in length, near the 10 mm length.



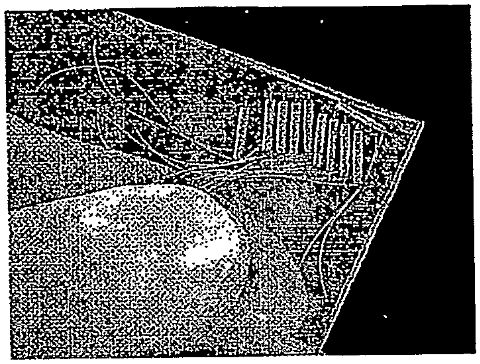
The Encoded Region has to have several millimeters spacing (Guard Spacing) from other Ferro magnetic objects that are placed at or near the Encoded Region. The same is true when the shape or the shaft diameter is changing at either side of the Encoded Region.

Primary Sensor Material Suggestion

Rank	DIN	Specification
1	1.2721	50NiCr13
2	1.4313	X4CrNi13-4
3	1.4542	X5CrNiCuNb16-4
4	1.2787	X20CrNi17-4
5	1.4034	X46Cr13
6	1.4021	X20Cr13
7	1.5752	14NiCr14
8	1.6928	S155

Secondary Sensor unit: MFS coil dimensions

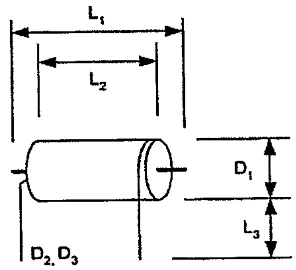
NCTE is using very small inductors (also called: Magnetic Field Sensors or MFS) to detect the magnetic information coming from the primary sensor. The dimensions and specifications of these coils are adapted and optimized for the PCME sensing technology and the targeted application.



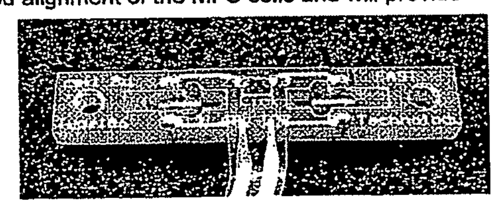
The MFS from NCTE come in two different sizes (6 mm body length and 4 mm body length), and two different temperature ranges (standard temperature range till 125 deg C, and high temperature range till 210 deg C). Further dimensions are listed in the table below.

The electrical performance of the 4mm and the 6 mm coil are very similar, whereby one is a bit longer and the other has a slightly larger diameter. The wire used to make the coil is relatively thin (0.080 mm in diameter, incl. insulation) and is therefore delicate.

Specification	Sym	6mm Coil	4mm Coil	Unit
Length overall	L_1	8.00 +/-0.2	6.1 +/-0.2	mm
Body length	L_2	6.00 +/-0.2	4.1 +/-0.2	mm
Wire length	L_3	>65	>65	mm
Coil diameter	D_1	1.27 +/-0.1	2.05 +/-0.15	mm
Cu wire dim	D_2	0.065	0.065	mm
Coated wire	D_3	0.08 +/-0.005	0.08 +/-0.005	mm
Resistance	R	7.4 +/-0.5	10.5 +/-0.7	Ohm



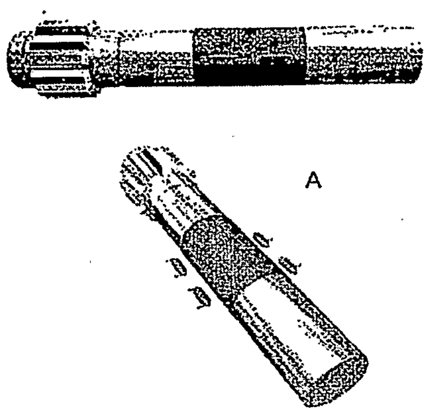
In applications where two axial aligned MFS coils are needed (for example to compensate for the effects of the Earth Magnetic stray Field, also referred to as EMF) they can be placed inside a specially milled PCB. This type of assembly (here shown with the two MFS coils before potting them) guaranties good alignment of the MFS coils and will provide reasonable mechanical protection.



How many MFS coils are needed and where they should be placed (in relation to the Encoded Region) is depending on the available physical spacing in the application and on which physical parameters should be detected or should be eliminated. In the classical NCT sensor design coils in pairs are used (see picture above) to allow differential measurement and to compensate for the effects of interfering magnetic stray fields.

Secondary Sensor Design: MFS arrangement

Depending on the sensor environment and the targeted system performance, a NCTE sensor system can be built with only one MFS coil or with as many as 9 MFS coils. Using only one MFS coil is only advisable in a stationary measurement system where no magnetic stray fields are present. Nine MFS coils may be needed when high sensor performances expected and the sensor environment is complex (for example: interfering magnetic stray fields are present and interfering Ferro magnetic are moving nearby the sensor system).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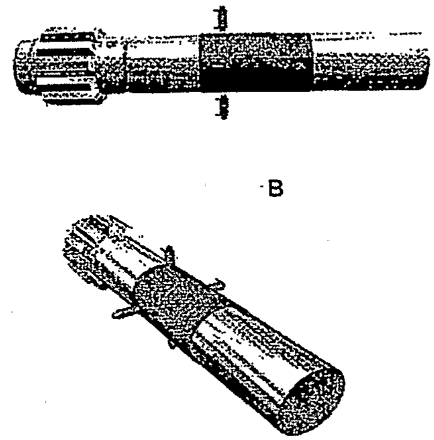
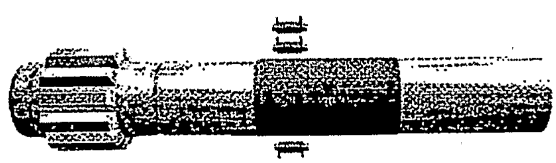

B

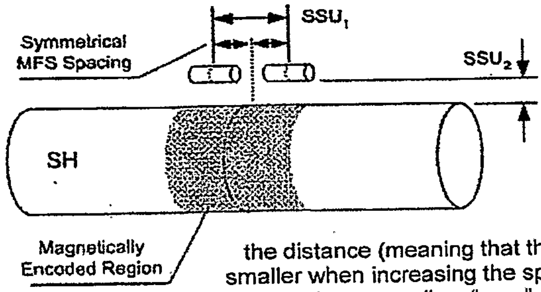
There are three axial directions with which the MFS coils can be placed near the magnetically encoded region: Axial (parallel to the SH), Radial (sticking away from the SH surface), and Tangential. The axial direction of the MFS coil and the exact location in relation to the Encoding Region defines which physical parameters are detected (measured) and which parameters are suppressed (canceled-out).

In circumstances where limited axial spacing is available to place the MFS coils near or at the Encoding Region (see above drawing, option A), the MFS coils can be placed radial, slightly off-centered to the Encoding Region (option B).



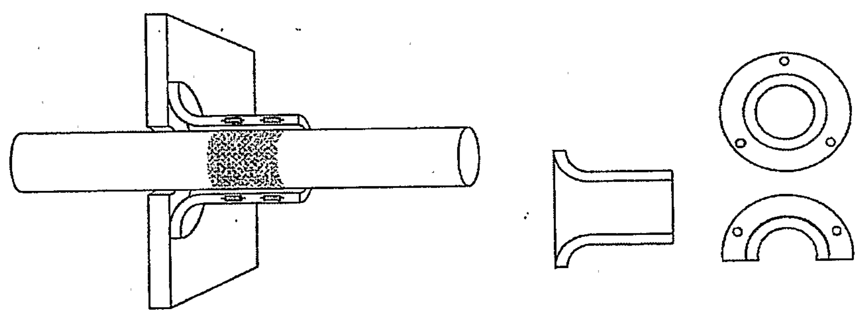
When limited axial spacing is available then single MFS-coils can be used with a "piggy-back" MFS-coil to eliminate the effects of parallel interfering magnetic stray fields (like the Earth Magnetic Field, **EMF**).

In the classical (standard) NCTE sensor design the Secondary Sensor Unit (Two MFS coils facing the same direction) is placed in axial direction (parallel) to the SH, and placed symmetrical to the center of the magnetic encoded region.



The critical dimensions are: Spacing between the two MFS coils (SSU_1), and the spacing between the SH surface and the MFS coil surface (SSU_2). When changing SSU_2 the signal output of the sensor system will change with the square to the distance (meaning that the output signal becomes rapidly smaller when increasing the spacing between the SH surface). SSU_2 can be as small as "zero" mm, and can be as large as 6 mm, whereby the signal-to-noise ratio of the output signal worsens at larger numbers.

The spacing between the two axially placed MFS coils is a function of the magnetic encoding region design. In the classical NCTE sensor design SSU_1 has to be 14 mm. This spacing can be reduced by several millimeters when accepting that the Rotational Signal Uniformity (**RSU**) performance will worsen to some degree.



The above drawing shows a typical MFS coil holder as used in gearbox applications. Note: The second MFS-coil pair improves the sensors capability in dealing with shaft run-outs (radial movements of the shaft during operation).

PCME Sensor Electronics

While it is possible to build a precision force (like torque) sensor with one MFS (Magnetic Field Sensor) device only, the PCME senor system performances greatly improve when using 2 or more MFS devices in the Secondary Sensor Unit. For example, by using two MFS devices, placed in reversed order to each other it is possible to enhance the targeted sensor signal while simultaneously the EMF (Earth Magnetic Field) or any other uniform and parallel magnetic stray field will be canceled.

The achievable performance of such a signal processing approach depends greatly on the matching of the actual electrical specifications between the used MFS devices in the Secondary Sensor Unit.

The here described inventions are electrical circuit designs that assure that the MFS devises and the attached first stage SCSP (Signal Conditioning & Signal Processing) electronics are automatically matched to each other. Meaning that when using such a circuit design as here described, any signal gain differences between two or more signal channels, caused by specification differences of the MFS devices, or caused by tolerances of the used active and passive electronic components, will be evened out.

This invention is specifically dedicated for applications like Motor Sport, Racing Cars, Engine Test Stands, or Power Tools. All of these applications have one thing in common: Lots of high frequency signal noise (signal frequencies of 100Hz and higher).

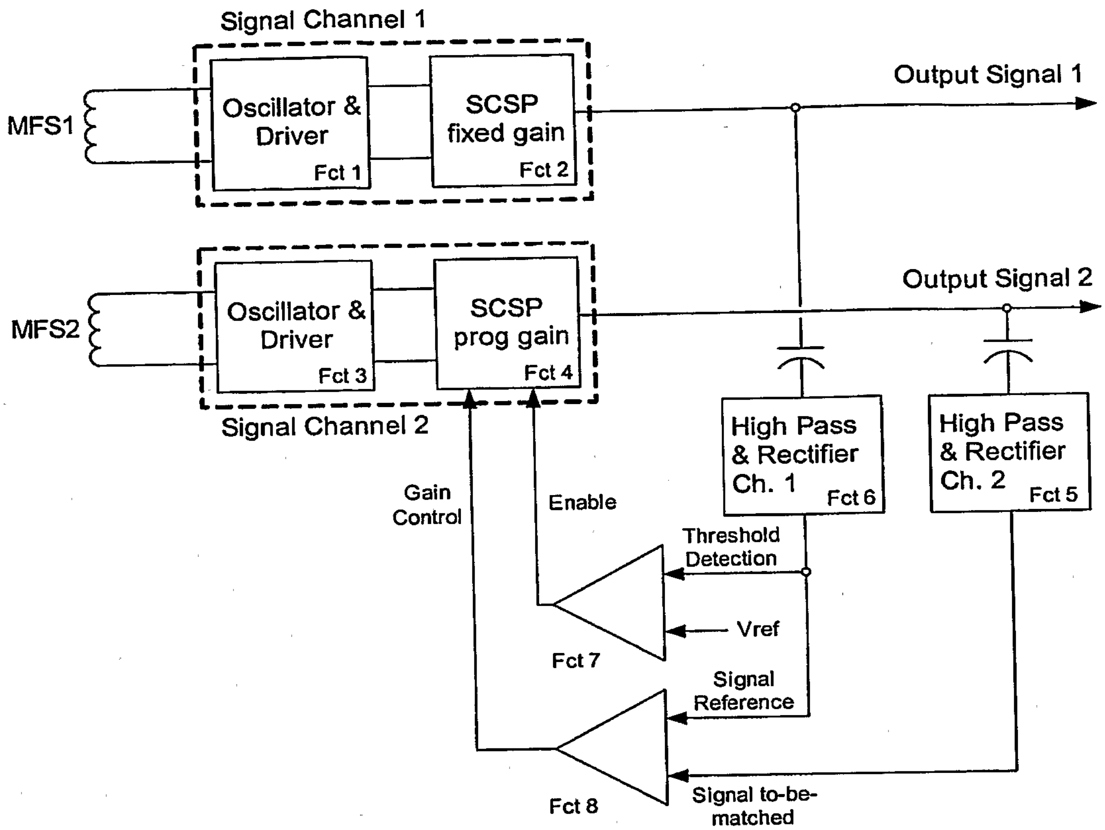
Automatic Gain Matching (AGM)

This solution, "Automatic Gain Matching" relies on the fact that there will be a lot of noise present when using this sensor in the targeted application: Motor Sport, Racing Cars, or Engine Test Stands.

When in operation the mechanical forces measured (like torque) will be very dynamic. As the used MFS devices are placed around the same Primary Sensor region, the targeted output signals should be all of the same amplitude.

Interfering magnetic stray fields have a DC or low frequency characteristics (typically 5 Hz or less). For example, a racing car that is driving around a racing track will not turn around the car in relation to the Earth Magnetic Field faster than 5 times per second (and that in itself will be astonishing already).

In the here shown example (see below) the signal gain of channel one is fixed while the signal gain of channel two can be changed through an applied voltage (Gain Control).



Drawing 1A: Automatic and active channel-gain-matching by comparing the high frequency signal amplitudes of the two used channels.

The output signals of each channel (Block Function 2 and Block Function 3) are then passed-through a high pass filter (Block function 6 and Block Function 5). The desired cut-off frequency of this filter has to be defined by the specifics of the application where this solution will be used. In a typical Motor Sport application this frequency could be 100 Hz or more (like 500 Hz).

The rectified signals from Block Function 6 and 5 are then compared to each other in Block Function 8. When both signals match each other (same values) then there will be a neutral Gain Control Signal (the gain of Block Function 4 will not change). In case the signals differ then the Gain Control signal will follow proportionally to the detected signal miss-match, in amplitude and polarity.

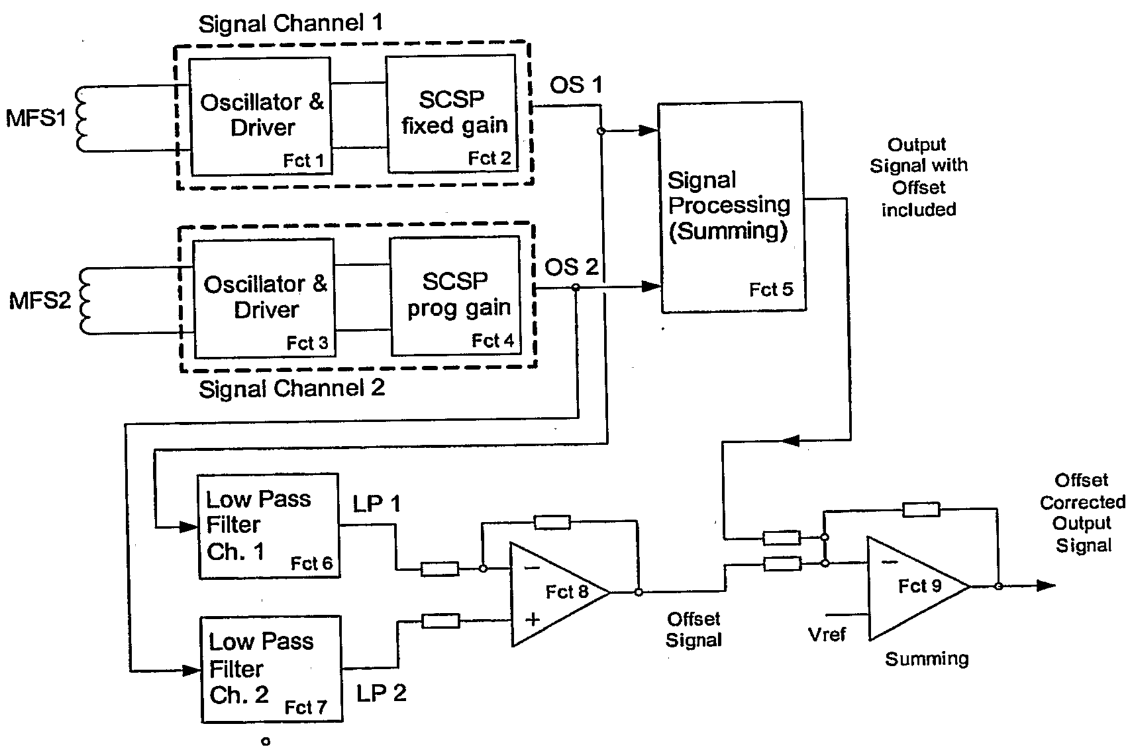
By changing the gain of Block Function 4 the system will be tuned to the point where both input channels (1 and 2) have overall matching gain specification (includes possible tolerances in the MFS devices).

In case there is no high frequency signal noise present (meaning that there is no signal present that is needed to detect gain differences in Channel 1 and 2) then the threshold detector Block Function 7 will disable the gain control function of Block Function 4. This solution prevents the AGM system from becoming instable.

The Invention 2: Automatic Offset Compensation (AOC)

In mobile applications where the magnetic principle based sensing device is surrounded by Ferro magnetic materials (example: engine block and gear box assembly), magnetic stray fields (like the Earth magnetic field) will be distorted. This will influence the systems ability to cancel-out formerly uniform (parallel) magnetic stray fields. Meaning the standard SCSP electronics will be unable to detect and eliminate the effects of EMF signal, for example.

In motor sport application where the car is driving around a closed-loop track, it is possible to detect the effect of the EMF (Earth Magnetic Field) caused signal offset by using low pass filters.



Drawing 2A: Block diagram of an active EMF canceling solution for applications where the EMF signal will be distorted.

Invention 1: Ability to actively detect and compensate the gain miss-matches in PCME multi-channel signal stages. This invention does not require any calibration and can be realized by using analog signal computation, or mixed signal computation, or full digital signal computation.

Invention 2: There is no need of using "mapping" solutions or an additional signal channel to detect and measure the true presents of the EMF signal. This solution

is using the already present signals and is extracting the information (influence of the EMF) through a very simple computation.

Target Applications

Applications where there is a high signal dynamic and a signal noise content > than 50 Hz :

- Motor Sport applications
- Engine Test Stands
- Impact and Impulse Power Tool Applications
- Marine Drive Shaft Application
- Avionic transmission control (Helicopter drive shafts)

In this report are a number of "new" acronyms used as otherwise some explanations and descriptions may be difficult to read. While the acronyms "ASIC", "IC", and "PCB" are already market standard definitions, there are many new terms that have been created in relation to the magnetostriction based NCT sensing technology.

Acronym	Description	Category
ASIC	Application Specific IC	Electronics
ASC	Automatic Slope Control	Sensor System
DF	Dual Field	Primary Sensor
EMF	Earth Magnetic Field	Test Criteria
FS	Full Scale	Test Criteria
Hot-Spotting	Sensitivity to nearby Ferro magnetic material	Specification
IC	Integrated Circuit	Electronics
MFS	Magnetic Field Sensor	Sensor Component
NCT	Non Contact Torque	Technology
PCB	Printed Circuit Board	Electronics
PCME	Pulse Current Modulated Encoding	Technology
POC	Proof-of-Concept	
RSU	Rotational Signal Uniformity	Specification
SCSP	Signal Conditioning & Signal Processing	Electronics
SF	Single Field	Primary Sensor
SH	Sensor Host	Primary Sensor
SPHC	Shaft Processing Holding Clamp	Processing Tool
SSU	Secondary Sensor Unit	Sensor Component

Sensor Host: Mechanic power transmitting shaft (for example produced out of Ferro magnetic material) that is the host (or carrier) of a Ferro magnetic sensor device.
Primary Sensor: Magnetically encoded section at the Sensor Host
Secondary Sensor: Magnetic pickup of the sensor information, emitted by the Primary Sensor

Sensor Aging: Unwanted signal slope reduction of the Primary Sensor due to physical mechanical overloads applied to the Primary Sensor, or due to other damages of the Primary Sensor.
"Total-Force" Technology: Sensing system technology that alerts the user when there are noticeable power losses in the torque sensing system

ASC = Automatic Slope Control

The Non-Contact PCME sensing technology requires that the Secondary Sensor is placed at a fixed distance in relation to the Primary Sensor. Explanation: The "radial" spacing between the Secondary Sensor module and the Sensor Host surface (or shaft surface) has to be kept constant.

The signal strength, emitted from the Primary Sensor, will degrade rapidly the further away the receiving Secondary Sensor module is placed. In case of an application where the entire sensor system is exposed to strong vibrations (example: Combustion engine, or impact power tools) it is possible that the PCME sensor output signal will show the effect of the system vibration in form of a signal amplitude modulation. The same could happen in an applications where changes in the ambient temperature has an effect on the mechanical position of the Secondary Sensor module in relation to the Primary Sensor location (example: different temperature expansions of materials used for the physical sensor design.

This issue can be controlled and dealt with by applying the proper care when designing the sensor system (using strong bearings, assuring that the temperature coefficient is matching for the different mechanical sensor modules / components). However, the circumstances may make it impossible to assure that the mechanical precision and stability required can be guarantied and therefore the "radial" spacing may vary during the use of the sensor system.

The here described invention provides a fully automatic compensation for the otherwise unwanted effects when the "radial" spacing is changing between the Secondary Sensor module and the Primary Sensor. This invention is called here: Automatic Slope Control or ASC.

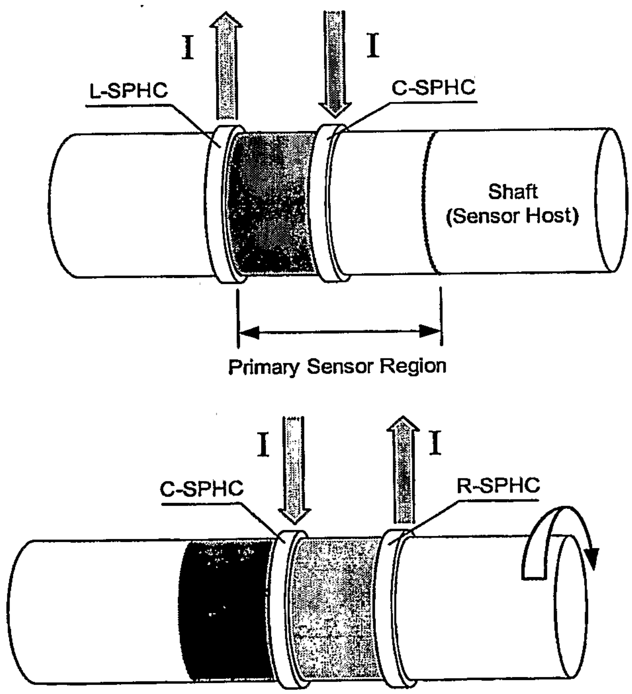
This invention is also capable to deal with the unwanted effects of sensor signal aging in case the sensor system has been exposed to mechanical overload. Explanation: In case the Sensor Host will be stressed to and beyond the point where "plastic" deformation of the Sensor Host is taking place, the PCME signal begins to weaken permanently (this phenomena is typical for many sensing technologies that rely on the principles of magnetostriction). This is here called "Sensor Aging").

The ASC technology is capable to compensate for the effects of sensor aging.

To achieve the ASC effect it is necessary to place a magnetic reference signal inside the Sensor Host. The Sensor Host will then carry the magnetic encoding of the PCME technology and a magnetic reference encoding in parallel to each other. It is the objective that the magnetic PCME encoding will continue to respond to the physical stresses applied to the Sensor Host, while the magnetic reference encoding will only react to the effects of sensor aging.

This ASC reference signal is placed in the SH during the PCME encoding process. Normally the PCME process is applied to the Sensor Host (SH) while the SH (or shaft) is in relaxed state (no mechanical stresses are applied to the SH). In case of the ASC technology, two PCME encoding processes will take place in succession (not in parallel) while one PCME process takes place in "relaxed" state, the other PCME process takes place while a known mechanical force (like torque) is applied to the SH.

By applying mechanical stress (like a torque force) to the SH during the PCME encoding process, the output signal of the final sensor system will have an electrical offset that is proportional to the applied mechanical stress.



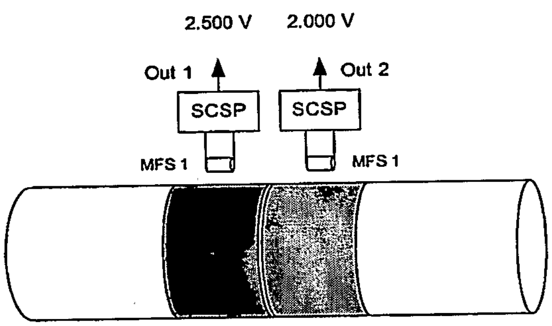
Encoding Step 1: PCME process applied to SH while no mechanical forces are applied to SH

Encoding Step 2: PCME process applied to SH while a known mechanical forces is applied to SH

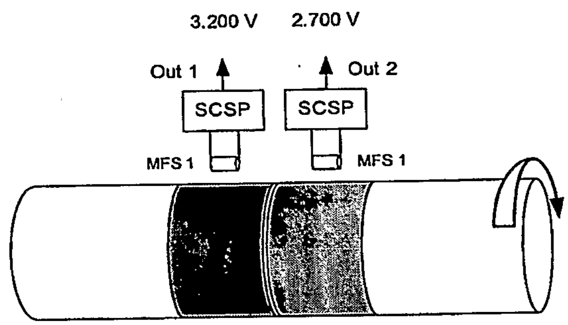
Drawing 1: A Dual PCME Field encoding is required to achieve the ASC effect. While one PCME encoding process happen while NO mechanical forces are applied to the SH, the other PCME encoding takes place while a known mechanical force (like torque) is applied to the SH. In principle there are no obligations in which order these process steps take place.

To recover the ASC reference signal, at least two MFS devices are needed that will form the Secondary Sensor Unit. It is important that the two MFS devices needed are mounted on the same frame to ensure that any change of spacing between the Secondary Sensor Unit and the Sensor Host (SH) will effect both MFS devices in exactly the same way.

It is also very important that the required SCSP (Signal Conditioning & Signal Processing) electronics for both channels (MFS1 and MFS2) are effected by the changes of supply voltages and ambient temperature changes in exactly the same quantitative way. Otherwise the ASC reference signal will not be reliable enough to achieve the desired performances.



PCME Sensor with ASC technology
when NO mechanical forces applied

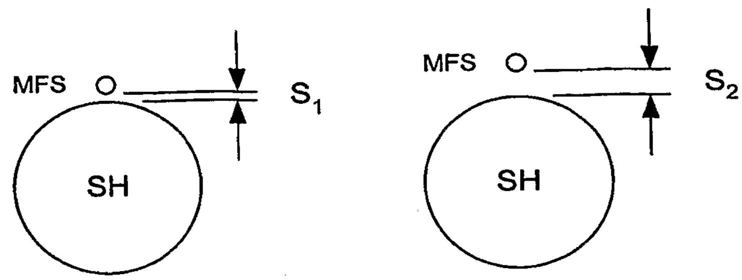


PCME Sensor with ASC technology
when specific torque force applied

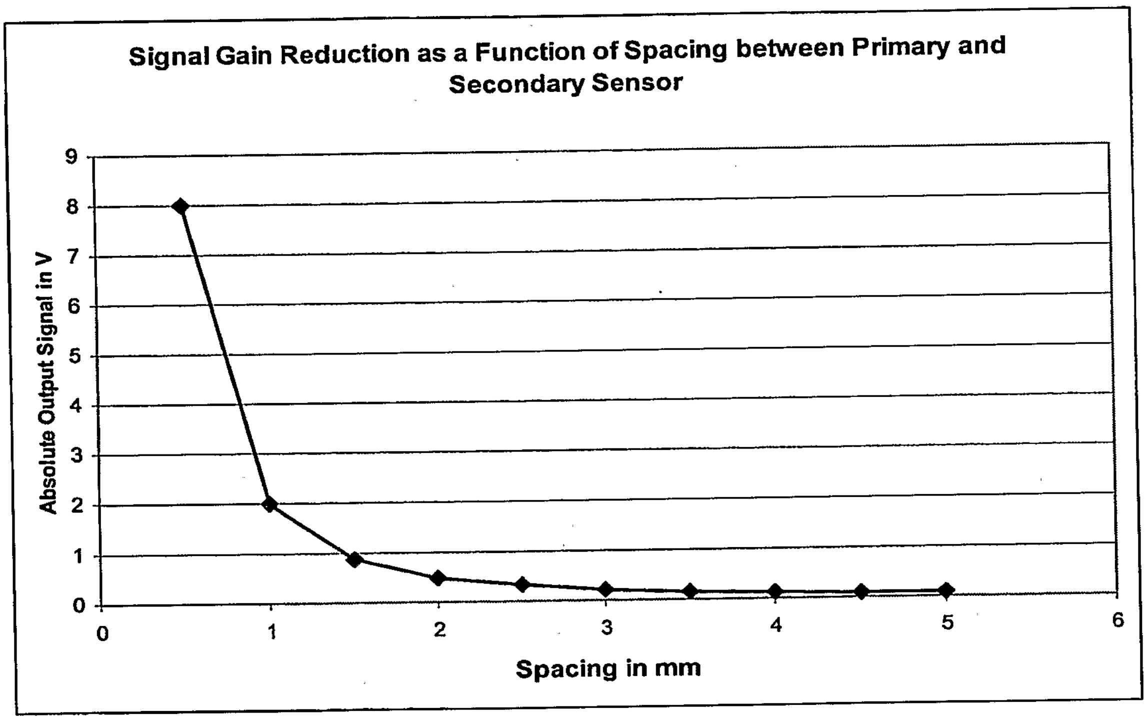
Drawing 2: Left picture: When the SH (Sensor Host or shaft) is in the relaxed state, the output signals from the two, independent working Secondary Sensor & SCSP (Signal Conditioning & Signal Processing) Channels (Output 1 and Output 2) reading the values: +2,500V and 2.000V. The difference between these two voltages is dependent on the applied mechanical force during the PCME SH processing, the gain setting of the SCSP electronics, and the spacing between the MFS and the SH-Shaft surface. In this example the difference is 2.500 V – 2.000 V = 0.500 V. This 0.500 V represent the ASC reference signal. Under normal condition the ASC reference signal remains constant.

Right picture: When applying a specific torque force to the SH the output voltages from both SCSP channels will change by the same amount. The change in output voltage is a proportional function of the applied mechanical force. However, the difference in the output Voltage from Channel 1 and Channel 2 remains constant (in this example: 3.200 V – 2.700 V = 0.500 V).

The signal increase from channel 1 (as a consequence of the applied torque force) is the difference between the two measurements: 3.300 V – 2.500 V = 0.700 V. The signal slope is a function of the spacing between the Primary Sensor (surface of the SH) to the Secondary Sensor (MFS device).

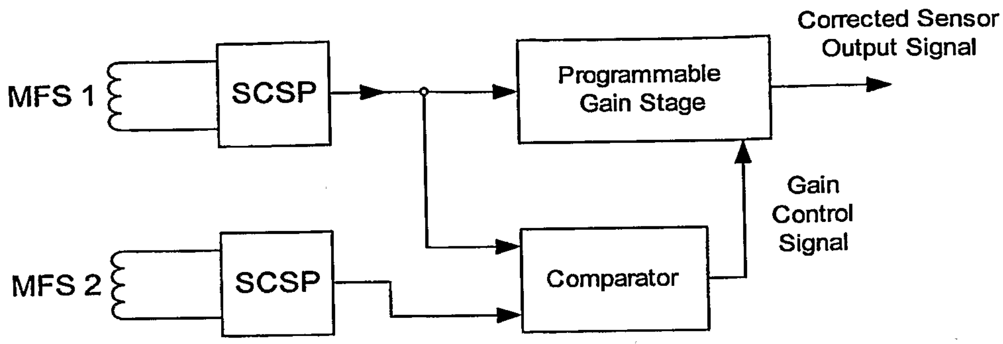


Drawing 3: As the spacing between the MFS (also called Secondary Sensor) is increasing (like from the values S_1 to the value S_2), the signal amplitude will drop.



Graph 1: With increasing spacing between the Secondary Sensor (MFS device) and the Primary Sensor (SH surface), the absolute signal amplitude will drop rapidly (function of the power to the spacing).

In the same way the signal amplitude will drop, so will the ASC signal. Note: The ASC signal is the difference between the output voltages from Channel 1 and Channel 2.



Drawing 3: Block diagram of the ASC electronics. In this simplified example the sensor signal, generated by the Secondary Sensor device: MFS 1, will be amplitude modulated in the module "Programmable Gain Stage". The difference between the signals MFS1 and MFS2 is processed in the module "Comparator". The output signal of the module "Comparator" is the "Gain Control Signal" of the Programmable Gain Stage. The larger the signal difference between MFS1 and MFS2, the lower the gain setting of the Programmable Gain Stage has to be. The lower the signal difference between MFS1 and MFS2, the higher the gain setting of the Programmable Gain Stage has to be.

With the increase of the gain setting, the Signal-to-Noise ratio will become poorer. Meaning that at some point the signal generated by MFS1 is so small that a high gain setting will amplify mainly the noise and consequently the resulting "Corrected Output Signal" is no longer of any use.

In this description "in-line" or "axial" positioned MFS devices have been used. However, this technology will work the same when using radial or tangentially placed MFS devises. Which way the MFS device has to be placed depends on what mechanical forces need to be measured and what type of mechanical force has been applied to the SH during one of the PCME encoding process.

The ASC technology is a true Non-Contact solution to detect and to correct changes of the PCME output signal amplitude caused by mechanical failures of the sensor system.

The ASC technology detects and corrects 100% the changes of the output signal amplitude, caused by sensor aging or by changes in the spacing between the Primary and Secondary Sensor. The space changing may be caused through mechanical damages in the sensor assembly, the effects of temperature (differences in physical expansion of the sensor material), or through mechanical vibrations in the sensor system.

The ASC technology will eliminate the need for sensors "gain"-setting calibration as the ASC reference signal gives a true representation of the sensor systems response to applied mechanical forces.

This technical solution does not require any more spacing on the SH. Meaning that the mechanical dimensions and the physical design of the "dual field" PCME sensor remains the same. There is no need to attaché any device or any substance on the SH and therefore the outstanding performances of the PCME sensor are not affected by the ASC technology.

The required electronics of the ASC solution is of low complexity and can be realized in analog signal processing technology or by using mixed signal (analog and digital) technology. When using the mixed signal approach there will be no need for any additional electronic component to implement the ASC technology. Meaning: no cost increase.

Benefits

The ASC technology can correct in real-time the output signal of a PCME sensor system. The output signal correction includes:

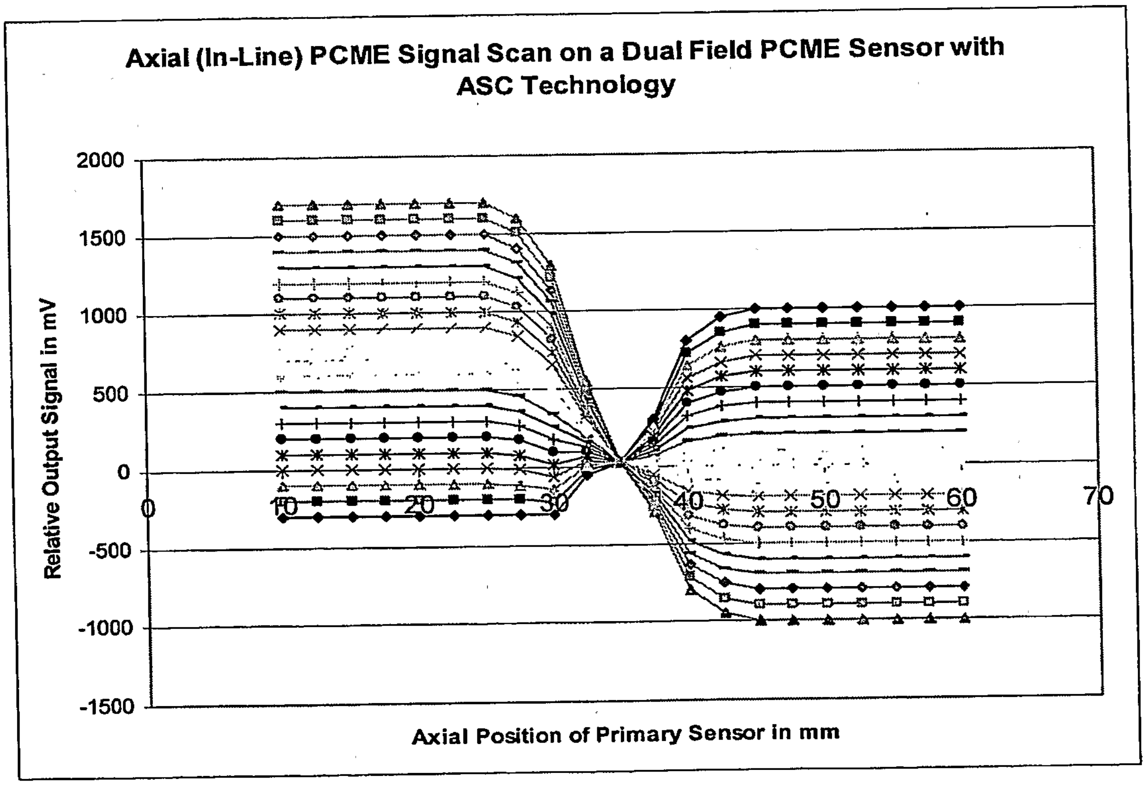
- ☐ Fully compensating the effects of unwanted changes in the spacing of the Secondary Sensor module during measurements
- ☐ Compensating the effects of senor aging, caused by applying a mechanical overload to the Primary Sensor device.
- ☐ Fully compensating the effects of gain changes in the SCSP electronics stages caused by the influence of ambient temperature changes.
- ☐ Eliminates the need for the sensors gain / slope calibration. The ASC reference signal can be used to define the actual sensor response to mechanical forces applied to the SH (or Primary Sensor).

The ASC technology may not add any costs in the actual sensor system and can be applied during the actual PCME encoding procedure.

Target Applications

The ASC technology is applicable to all PCME sensor designs where mechanical forces (like torque, axial forces, bending) or a position (rotational and linear) needs to be measured accurately. Particularly important is this technology for applications where there is a risk of mistreating the sensor system (detecting and compensating for the effects of applying a mechanical overload (resulting in Sensor Aging): Motor Sport, Industrial Drilling Applications, Impact and Impulse Power Tools.

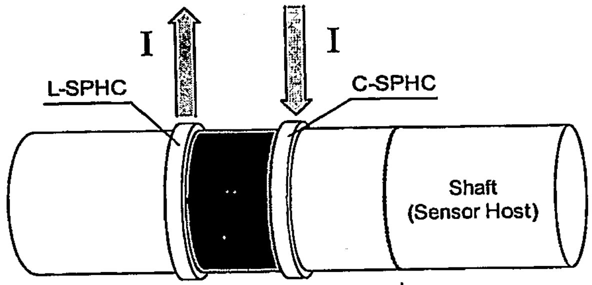
Background and Explanation
The drawing below shows the sensor system output signal as a function of the axial (in-line) location at the Primary Sensor region.



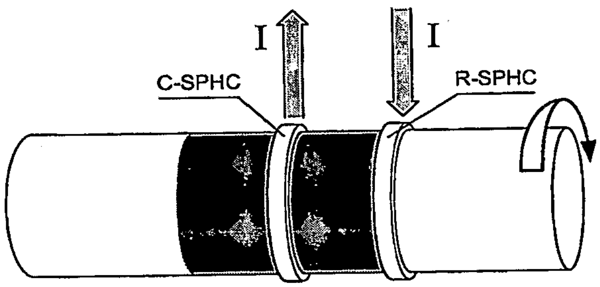
Graph 2: Sensor system output signal when moving one MFS device along the PCME encoded sections (Primary Sensor region). This graph has been generated from a Dual Field PCME sensor with reversed polarity encoding (process described in Drawing 1).

The reversed polarity encoding makes it simpler to cancel the effects of parallel / uniform magnetic stray fields, like the Earth Magnetic Field (EMF). This can be achieved by subtracting the output signals MFS1 from MFS2.

However, the ASC technology also works on a Dual Field PCME sensor with not reversed polarity encoding (see below).

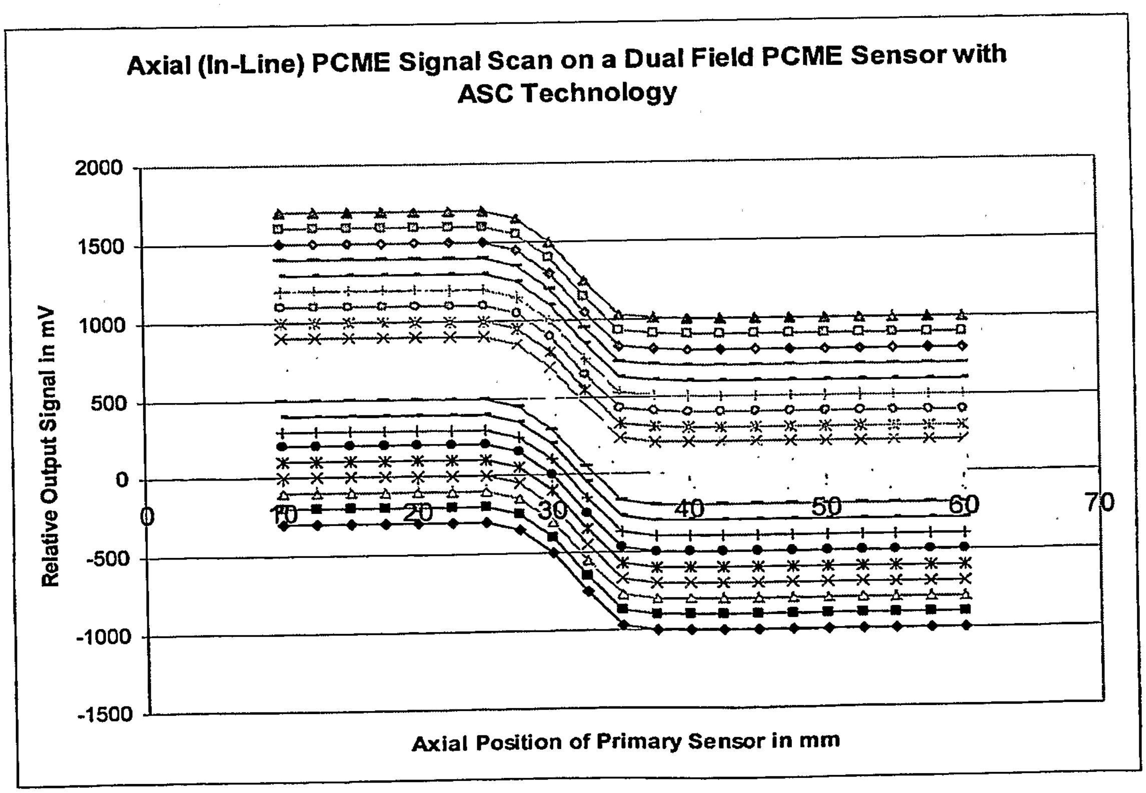


Encoding Step 1: PCME process applied to SH while no mechanical forces are applied to SH



Encoding Step 2: PCME process applied to SH while a known mechanical forces is applied to SH

Drawing 4: Dual Field, PCME processing, including ASC technology. The encoding polarity has not been reversed during the process.



Graph 3: Sensor System output signal when moving one MFS device axially along the Primary Sensor region. This graph comes from a Dual Field, not reversed polarity PCME sensor with ASC technology. The step function in the signal lines is caused by the PCME encoding while the sensor has been under mechanical stress (like torque).

Note that there is an area between the two parallel signal section that can not be used by the MFS devices as a signal pick-ups. In the drawing above the MFS 1 can be placed anywhere along the physical Primary Sensor positions: 10 mm till 25 mm. The MFS 2 can be placed anywhere from the axial position 36 mm to 60 mm. The area between the axial positions 25 mm to 36 mm is unusable for the ASC technology as the signal slope is changing (not stable).

Until now this report has described an ASC encoding process whereby only one PCME encoding step has been performed with physical load applied to the SH. It is possible to achieve a much larger signal step function when both PCME encoding steps are performed while a mechanical load is applied to the SH. However the mechanical load applied to the SH has to be in opposite direction to assure that the desired ASC reference signal can be generated.

Glossary

In this report are a number of "new" acronyms used as otherwise some explanations and descriptions may be difficult to read. While the acronyms "ASIC", "IC", and "PCB" are already market standard definitions, there are many new terms that have been created in relation to the magnetostriction based NCT sensing technology.

Acronym	Description	Category
ASIC	Application Specific IC	Electronics
ASC	Automatic Slope Control	Sensor System
DF	Dual Field	Primary Sensor
EMF	Earth Magnetic Field	Test Criteria
FS	Full Scale	Test Criteria
Hot-Spotting	Sensitivity to nearby Ferro magnetic material	Specification
IC	Integrated Circuit	Electronics
MFS	Magnetic Field Sensor	Sensor Component
NCT	Non Contact Torque	Technology
PCB	Printed Circuit Board	Electronics
PCME	Pulse Current Modulated Encoding	Technology
POC	Proof-of-Concept	
RSU	Rotational Signal Uniformity	Specification
SCSP	Signal Conditioning & Signal Processing	Electronics
SF	Single Field	Primary Sensor
SH	Sensor Host	Primary Sensor
SPHC	Shaft Processing Holding Clamp	Processing Tool
SSU	Secondary Sensor Unit	Sensor Component

Sensor Host: Mechanic power transmitting shaft (for example produced out of Ferro magnetic material) that is the host (or carrier) of a Ferro magnetic sensor device.
Primary Sensor: Magnetically encoded section at the Sensor Host
Secondary Sensor: Magnetic pickup of the sensor information, emitted by the Primary Sensor
Sensor Aging: Unwanted signal slope reduction of the Primary Sensor due to physical mechanical overloads applied to the Primary Sensor, or due to other damages of the Primary Sensor.

Patent Application: Wireless Sensor Power Supply and Signal read-out

Physical parameter sensor devices, like torque sensors, are often used as self-contained, stand alone sensor units in industrial applications or in industrial / automotive assembly line applications. One disadvantage of a traditional sensor device is that for the electrical intercommunication between the sensor and the external control system, electrical wires are needed.

For example, in a car-tire shop the torque sensor device will be used for quality control and safety inspections. During the process of tightening the log-nuts on each car wheel the worker needs to ensure that the correct torque is applied to the log-nut. The worker has to ensure that the bolts are not over-tightened or under-tightened. More-and-more the market and legislation demands that the actual torque applied to a bolt will be documented and this information needs to be stored for future references. To achieve this, the worker could use a hand held torque sensor device that will be attached to the front-end of the fastening tool (for example torque wrench, or a pneumatic / electrical powered fastening tool).

A torque sensor device that would be connected to the control system by wires is highly impractical. The operator (shop worker) of such tool is moving quickly around the car and from one car to the next so that it will be only a matter of time when the wiring will be ripped of by accident. Alternatively the operator has to work most carefully to avoid damaging the measurement system and therefore will be very time inefficient to finish the task at hand.

The here described solution focuses on the most challenging part: supplying electrical power to the sensor device "wire-less" and being able to use the same principle to read-out the sensors measurement results.

This solution is applicable to all types of sensor principles, and is particularly suitable when using the a magnetic based sensor principle.

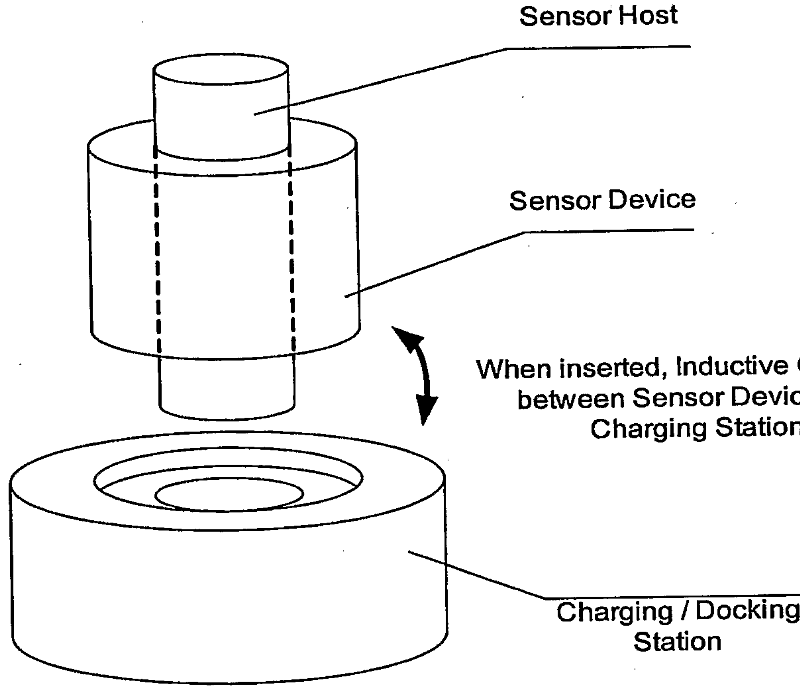
When not in use the sensor unit will rest in a specifically designed charging socket. Through inductive coupling methods the sensors on-board electrical storage device will be electrically charged.

In the case of PCME sensing technology the sensors current consumption is so low that a full charge of the on-board storage device will last from 8 hours (a full days of work) to several days.

When ever the sensor device is not in use it has to be placed back in the specific charging device. While resting in the charging device the connected control unit

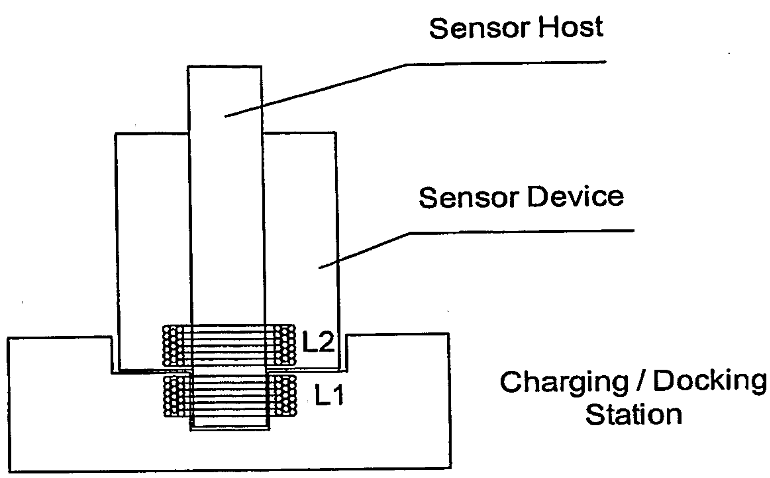
will read-out the measurement results and clear-out the sensors on-board memory.

The PCME magnetostriction based sensing principle relies on the reliability of the magnetic encoding of the mechanical power transmitting shaft (primary sensor). It is therefore critical that the chosen frequency of the inductive power coupling is high enough so that the magnetic encoding of the mechanical power transmitting shaft will not be damaged.

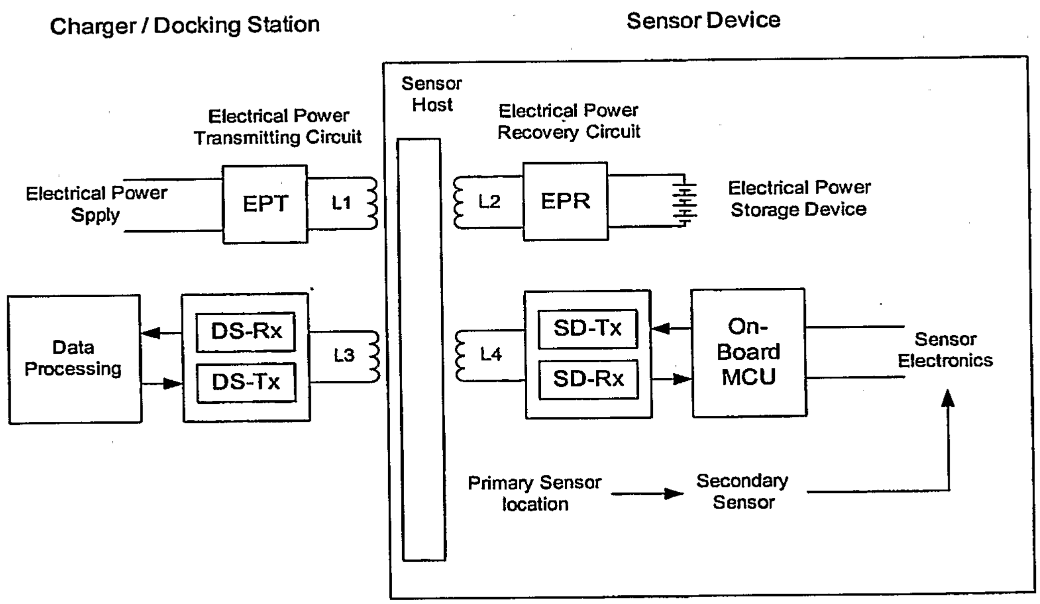


Drawing 1: Stand Alone sensor device (like a magnetic principle PCME sensor) that will be inserted into the Charging or Docking station. When inserted the magnetic inductive coupling takes place and allows electrical power transfer to the sensor devices and data communication from the sensor device to the docking station.

The optimal coupling frequency is dependent on the primary sensor shaft diameter (we assume that the primary sensor material is Ferro magnetic industrial steel). When the shaft diameter is less then 5 mm the coupling frequency has to be greater than 500 Hz to ensure no degrading of the primary sensors performances. The lower the inductive coupling frequency (when being below 500 Hz) the quicker the degrading of the sensor performance). At shaft diameters of 25 mm or more the inductive coupling frequency can drop to 250 Hz or even less.



Drawing 2: Built-in in the docking station is inductor L1 (Electrical Power transmitter and Sensor Signal Receiver), while built-in the sensor device is the inductor L2 (Electrical Power Receiver and Sensor Signal Transmitter).



Drawing 3: Block diagram of the functions: Wireless electrical power transmitter, and wireless data communication from and to the sensor device.

Although the inductive coupling devices for electrical power transmitting and data communication are separated, it is possible that these two functions can be placed together. In such a case only L1 and L2 are required.

Although the sensing principle is based on Ferro magnetic technology and therefore sensitive to externally applied strong magnetic fields (the primary sensor could be damaged or even erased), by choosing the right inductive coupling frequency it is possible to use the sensor host for four different functions at the same time:

- ☐ Transmitting of physical power (like torque)
- ☐ Being the host of the Primary Sensor
- ☐ Transmitter Medium for electrical power from the Docking Station into the Sensor Device
- ☐ Transmitting Medium for data communication between both, the sensor device and the docking station

The power transmission will happen at a frequency range of >250 Hz (preferable 500 Hz to 1 kHz) while the data communication between both devices (Docking station and Sensor Device) takes place at frequencies >>1 kHz (for example 10kHz or above).

In principle the data communication can happen at any frequency as long as the chosen frequency is not less than the electrical power transmitting frequency. However, by choosing a frequency that is identical to the electrical power transmitting frequency the data transfer rate will be relatively low. In addition the required signal separation circuit will be more complex than when choosing a much higher frequency for the data communication function.

The reason behind this is that the magnetic encoding of the PCME sensing technology is buried below the sensor host surface, deep enough so that the 500 Hz inductively coupled electrical power transmitting will not be able to reach and harm this permanently embedded magnetic field.

The higher the inductive coupling frequency the nearer the surface of the sensor host the magnetic field will travel.

Benefits

Wireless power transfer

No cables that can fail (maintenances free, high MTBF)

No hindrance to the operator as there are no wires in the way when using a sensor with this technology

No batteries that need to be replaced

Wireless data communication between the devices

Sensor Device can be completely enclosed and sealed of from dirt or any liquid

Lower manufacturing cost

No weak spot in the sensor design as there is no need for any opening or access holes / panels

No radio interferences as the whole system works in a relative low end of the frequency spectrum

Minimal load on the environment (no toxic material for batteries, low electro smog)

Low overall system complexity

Low cost, simple design, high functionality

Background and Explanation

It is not desirable to have any physical opening (for the wiring of the power supply or data communication or for switches and data entry keys) in the housing of a

mechanical force sensing unit. Such openings potentially allow unwanted substances (oil, water, dirt, gases, ..) to enter the sensor unit when not sealed properly which will interfere with the sensor systems performance and expected life time. The physical "openings" of such a sensor will increase substantially the manufacturing costs of the sensor unit as well as the need for connection wires will limit and restrict the freedom of how and where the sensor unit can be use.

The electrical supply of a self-contained sensor device can be either generated by the sensor unit itself or can be provided by an on-board electrical power storage device.

On-Board Electrical Power Generating

In many applications the mechanical force transmitting shaft of the sensor unit will rotate during the measurements. In some applications the mechanical forces that need to be measured will change very regularly in repetitive patterns. Where these criteria's are fulfilled (either rotating shaft or regular changing mechanical force patterns) an on-board mechanical driven electrical power generating system can be used.

Even so the required electrical power is very small; any direct or indirect mechanical principle based power generating will generate "losses" in the sensor unit. The consequences in the measurement accuracy have to be fully understood before applying such a power supply technology.

Most practical is the generating of electrical power in sensor units where the sensor shaft is rotating in relation to the sensors housing. To minimize the possible impact on the measurement accuracy the power generator has to be placed at the sensors "input" or "supply" side of the mechanical force.

Solar-Light Power

As the overall sensors power consumption is very low. Therefore using electrical solar power cells can be used where light is available at the location where the sensor unit will be used.

Inductive Supply

An on-board, maintenance free, high capacity electrical storage device (like "Gold Caps") will provide enough electrical power for the desired sensors working period (like 8 hours for a full days work or 2 hours for a very specific tasks). The capacity will be recharged through electrical inductance coupling when the senor system is placed into a specific charging cradle.

The electro magnetic coupling frequency is high enough so that the primary sensor will not be accidentally demagnetized (frequency equal or higher than 250Hz).

Long-Life Electrical Power Storage On-Board

Today there are electrical power supply devices available that have an incredible high power density. As the overall electrical power consumption of a PCME sensor is very low, it is possible to design and construct a sensor device that has a life-time battery built in lasting several months.

In desired such a Long-Life battery can be made replaceable. But such a design will carry all the disadvantages described earlier.

A low-power consuming on-board micro controller can further preserve the electrical power consumption of the sensor device by detecting when the sensor is not in use and therefore put the sensor device in sleep mode or standby mode. Such a technique will prolog the on-board battery life-time to 2 years or even longer before the battery or the entire sensor needs replacing.

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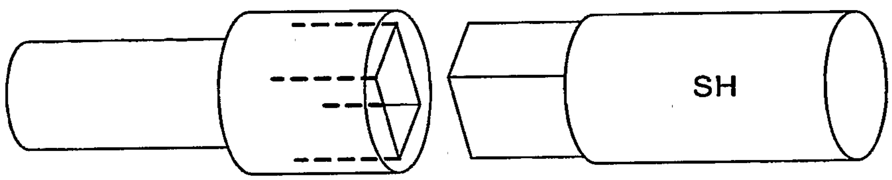
Total-Force

The most critical factor to measure torque accurately is the alignment and mechanical interface of the torque sensor with the input and output shaft. When using a stand-alone torque sensor device in an industrial application, this sensing device has to be connected to the power input and power output shafts by using either standardized interface adapters or using a customized solution. Typical standard interface formats are male and female square ends, or round shaft ends with key-stone couplings.

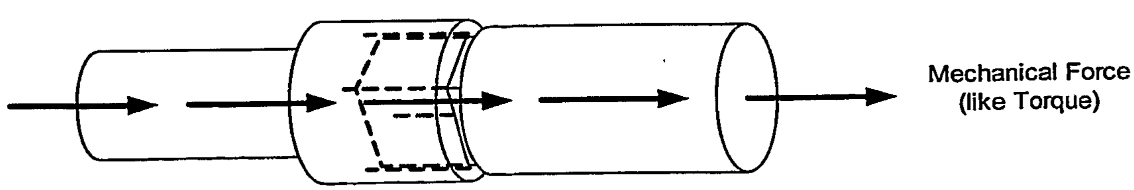
Mechanical Power Coupling using Square Adapter



Drawing 1: Typical mechanical coupling. In this example a mechanical square interface. The right part of this interface could be the Sensor Host (SH) of a PCME non-contact force sensor.

When using such a straight forward standard mechanical interface coupling the mechanical forces applied to the torque sensor will path through the sensing device as torque forces and as bending forces. The bending forces are caused by the non-ideal mechanical interface couplings on either side of the torque sensor. And it is the bending forces that will reduce the sensors accuracy by several percent. Even when using a high performing class 1 torque sensor the torque measurement result may be by 3% to >12% inaccurate because of the mechanical coupling issues.

It is the objective that the mechanical force (like torque) travels centric through the mechanical couplings



Drawing 2: When the two adapters have been inserted to each other it is the desire of the user that the mechanical force (like torque) is passing through the two couplings symmetrically (symbolically shown here through the center of the shafts and the couplings).

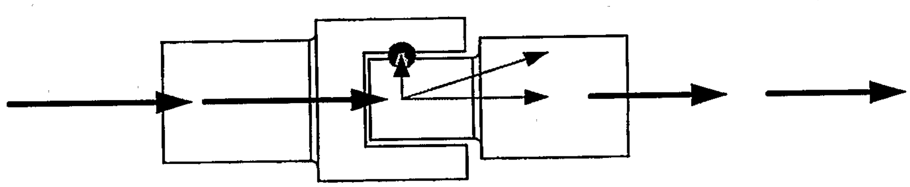
To ensure that the torque forces available from the power source (input shaft) are

recognized by the torque sensor to 100%, the torque forces have to enter and to leave the torque sensor device centric in relation to the measurement shaft. For example when using a round interface adapter with key-stone coupling, some of the mechanical forces (torque) will enter the input shaft in an angle, causing that the "torque" force becomes at least in part "bending" force. Although the entire mechanical forces will be transmitted through the sensor (depending on the used bearing support and sensor mounts), the sensor will NOT recognize all of these forces as torque.

Assumed Ideal Coupling

Real Non-Symmetric Mechanical Force Coupling

Drawing 3: In the ideal case it is assumed that the transmitted torque forces are coupled symmetrically (left picture, cross section view of the coupling) while in reality the torque forces are transmitted non-symmetrically through the "jamming" coupling (right picture, cross section view of the coupling).



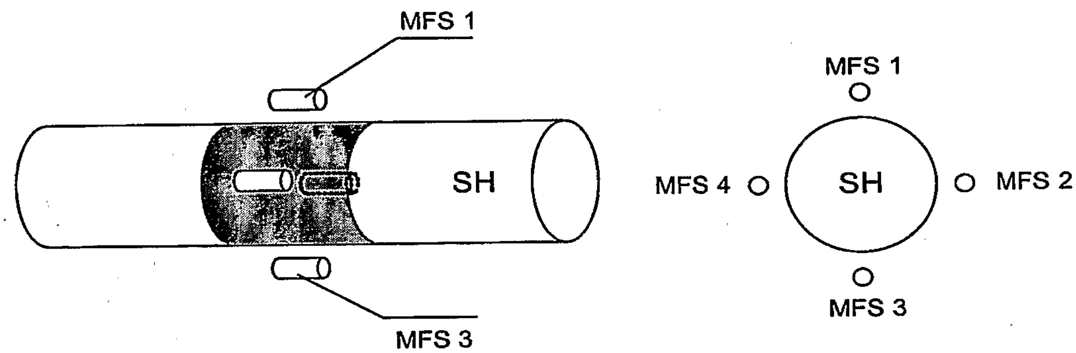
Transfer (Conversion) of Torque Force into Torque + Bending Force

Drawing 4: Side view of the coupling: Depending on how the forces are transmitted through the mechanical square interface (does the mechanical coupling happen through 2, 3 or more physical connections inside the coupling?) the torque force entering from the left will be converted into a bending force and a torque force: The torque force has been divided into two different type of mechanical forces.

The here described invention, called "Total-Force" is capable of sensing and measuring ALL of the applied mechanical forces (torque, bending, sheering, pushing, pulling,) and therefore can compute all of the transmitted torque more accurately then most other industrial torque sensing devices. The signal output can be either an accurate torque reading or a warning to the user that the torque measurement setup will result in incorrect reading when not modified.

The "Total-Torque" force sensor is therefore an easy-to-use torque measure device, ideal in industrial application where cost, simplicity, and small space are crucial.

The "Total-Force" technology measures the mechanical bending stresses at the power transmitting sensor shaft at several different locations around the shaft. The measurement results are then computed by an on-board MCU. The user can then chose in what format he would like to process the information: Bending forces only, Torque forces only, axial mechanical forces (pushing or pulling) or All-Torque.

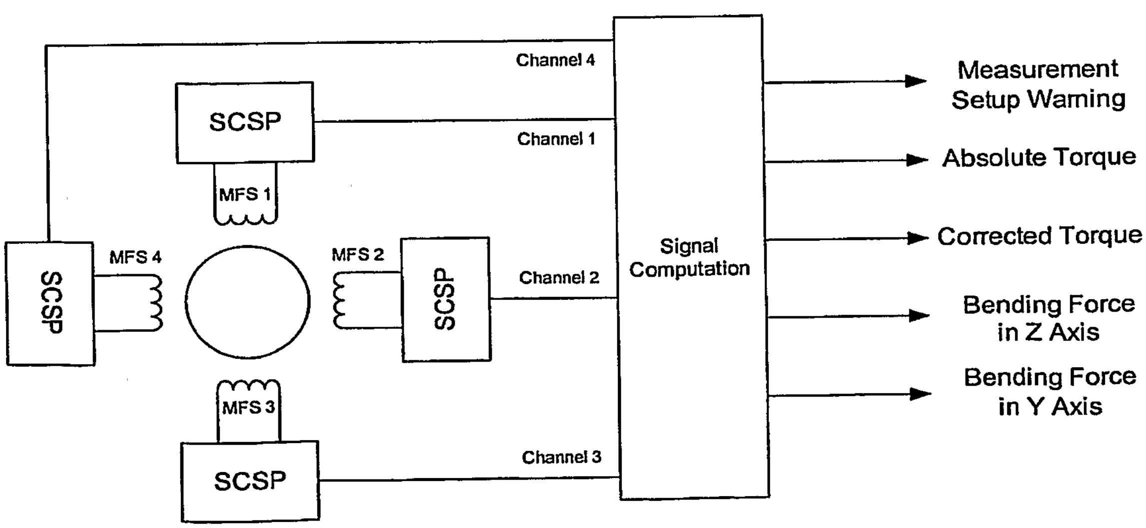


Magnetically Encoded Region (Primary Sensor)

Side View of the Sensor Design

Drawing 5: In this example the Secondary Sensor Units (MFS) are placed at 90 deg intervals around the Primary Sensor region. Alternatively the same effect can be achieved by using only 3 sets of MFS devices and placing them at 120 deg to each other around the SH. In that case the signal computation is more complex.

Under ideal circumstances (when the mechanical force is transferred symmetrically through the couplings and the SH) only one Secondary Sensor Unit (one MFS set) is needed. To built a Total-Force sensor the bending forces have to be measured as well to be able identifying non-symmetrical force transfer. Therefore a number of MFS devises are placed symmetrically around the Primary Sensor.



Drawing 5: Block Diagram of Total Force systems electronics. The Signal Computation unit can be realised in analogue, mixed signal, or digital technology. The computation processes are simple and described below.

When calculating the average value out of the 4 signal sources ((Channel 1 + 2 + 3 + 4) / 4 = Torque) the resulting value is the absolute (true) transferred torque through the Primary Sensor Region (not corrected torque value).

When processing the signals from the Secondary Sensor devices that are placed opposite to each other (Channel 1 and Channel 3, or Channel 2 and Channel 4) the system can accurately define the present bending forces present in the Primary Sensor region. The calculated bending forces are passed-on to the signal outputs: Bending Force in Z axis, and Bending Force in Y axis.

When detecting that the calculated bending forces exceed a certain percentage of the calculated torque forces then a warning signal is made available (Signal Output: "Measurement Setup Warning"), telling the user that the torque reading-error exceeds a predefined value. In this case the user has the option to make corrections to the coupling setup in order to reduce this torque measurement error.

In case the exact dimensions and the exact physical behavior of the used mechanical couplings are known then the Signal Computation unit can correct the torque reading and convert back the unwanted bending forces reading into torque forces reading. The resulting value, "Corrected Torque" is the passed-on to the according signal output. Note: The mechanical sensor system setup has to be fully understood before the "Corrected Torque" signal can be used.

Lowest computational requirements are needed when the mechanical stresses are detected and measured at every 90 deg around the sensor shaft. However, the same measurement results can be achieved when using three sensors, placed at 0 deg, 120 deg, and 240 deg around the shaft. In this case the computational requirements are considerably higher.

The "True Torque" sensing technology allows to identify torque losses or power losses inside a stand-alone force sensor device. The torque losses are caused through poor mechanical coupling as used in many industrial applications.

The "True Torque" technology does not require any more spacing in an existing non-contact sensor system, like a PCME sensor device. Nor are any changes required to the Primary Sensor region (or SH).

The "True-Torque" technology operates by using an existing PCME encoded shaft (no changes in the SH processing are needed), therefore no cost adder.

The "True Torque" technology operates in real time and does not slow down any measurement operation.

The industrial user, who is not very familiar about how to setup correctly a torque measurement system will benefit greatly by the "Measurement Setup Warning" signal. Until now the user had little or no idea that the torque measurements he did are incorrect, even so he was using a high precision and costly torque sensor system.

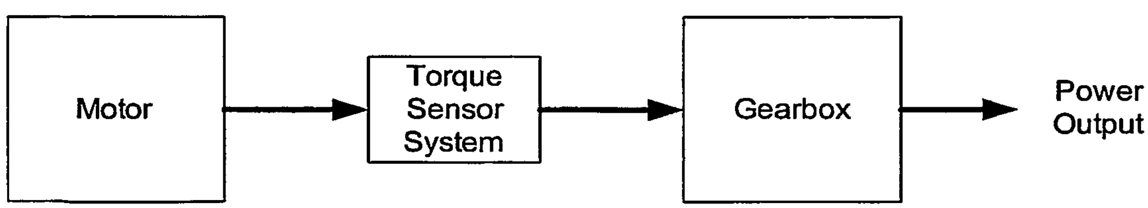
The "True Torque" technology allows the user to purchase "low budget" torque sensor systems as he is now able to achieve much higher measurement accuracy (better than one percent) with this technology than when using high precision torque sensors in a poor mechanical setup. Without "True Torque", in a typical industrial torque-sensor system setup, the achievable measurement accuracy may be only 5% or worse.

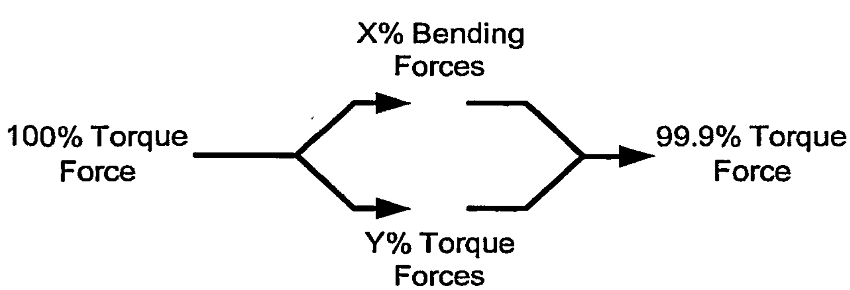
When ever a stand-alone mechanical force sensor device will be used and integrated into a measurement setup, like:

- ☐ Industrial calibration and maintenance applications (Gearbox testing, Motor testing, power transition testing).
- ☐ Laboratory applications (calibrations and measurements)
- ☐ Motor Test stand applications
- ☐ Automotive power transmissions
- ☐ Power tool calibration
- ☐ Power tool torque adapter

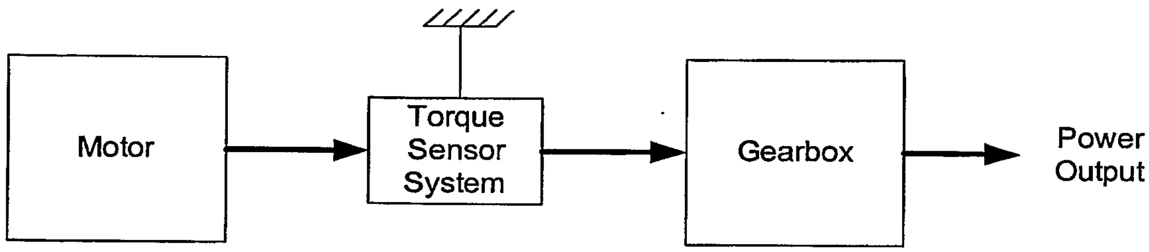
Background and Explanation

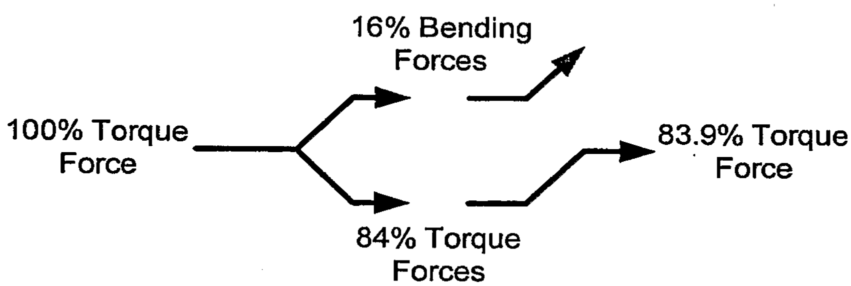
In an ideal system setup (typical example shown below) the torque forces applied to a sensor system, and the torque forces that are available at the sensor system are almost identical. In reality there are always losses of some kind, even so these losses might be very small.





Drawing 6: This picture demonstrates how torque forces coming from a power source, like a motor, may be split into torque-forces and bending-forces when using a separate (stand-alone) torque sensor system. The reason for this unwanted force conversion are none-ideal mechanical couplings at the sensor input and the sensor output. However, in this example almost all of the mechanical forces that are passed through the sensor system turn into torque forces again and very little power has been lost.





Drawing 7: In applications where the "stand-alone" torque sensing system is mechanically fixed to a separate fixture, the risk is very high that some or all of the converted forces (into bending forces) will be lost. Meaning that the Gearbox receives noticeably less power then the motor has provided.

The "Total Force" technology will make the user aware about this power loss so that he can correct coupling problems.

In this report are a number of "new" acronyms used as otherwise some explanations and descriptions may be difficult to read. While the acronyms "ASIC", "IC", and "PCB" are already market standard definitions, there are many new terms that have been created in relation to the magnetostriction based NCT sensing technology.

Acronym	**Description**	**Category**
ASIC	Application Specific IC	Electronics
ASC	Automatic Slope Control	Sensor System
DF	Dual Field	Primary Sensor
EMF	Earth Magnetic Field	Test Criteria
FS	Full Scale	Test Criteria
Hot-Spotting	Sensitivity to nearby Ferro magnetic material	Specification
IC	Integrated Circuit	Electronics
MFS	Magnetic Field Sensor	Sensor Component

NCT	Non Contact Torque	Technology
PCB	Printed Circuit Board	Electronics
PCME	Pulse Current Modulated Encoding	Technology
POC	Proof-of-Concept	
RSU	Rotational Signal Uniformity	Specification
SCSP	Signal Conditioning & Signal Processing	Electronics
SF	Single Field	Primary Sensor
SH	Sensor Host	Primary Sensor
SPHC	Shaft Processing Holding Clamp	Processing Tool
SSU	Secondary Sensor Unit	Sensor Component

Sensor Host: Mechanic power transmitting shaft (for example produced out of Ferro magnetic material) that is the host (or carrier) of a Ferro magnetic sensor device.
Primary Sensor: Magnetically encoded section at the Sensor Host
Secondary Sensor: Magnetic pickup of the sensor information, emitted by the Primary Sensor
Sensor Aging: Unwanted signal slope reduction of the Primary Sensor due to physical mechanical overloads applied to the Primary Sensor, or due to other damages of the Primary Sensor.
"Total-Force" Technology: Sensing system technology that alerts the user when there are noticeable power losses in the torque sensing system

NCTENGINEERING GMBH

What is claimed is:

1. Torque sensor, comprising:

a first sensor element with a magnetically encoded region; and

a second sensor element with at least one magnetic field detector;

wherein the first sensor element has a surface;

wherein, in a direction essentially perpendicular to the surface of the first sensor element, the magnetically encoded region of the first sensor element has a magnetic field structure such that there is a first magnetic flow in a first direction and a second magnetic flow in a second direction;

wherein the first direction is opposite to the second direction;

wherein the first sensor element is a shaft;

wherein in a cross-sectional view of the shaft, there is a first circular magnetic flow having the first direction and a first radius and a second circular magnetic flow having the second direction and a second radius;

wherein the first radius is larger than the second radius;

wherein a sensor electronic is provided;

wherein the sensor electronic implements an automatic slope control;

wherein a wireless sensor power supply and signal read-out is provided; and

wherein a total force measurement element is provided.

2. Method of magnetizing an metallic body element, the method comprising:

applying at least two current pulses to the metallic body element such that in a direction essentially perpendicular to a surface of the metallic body element, a

magnetic field structure is generated such that there is a first magnetic flow in a first direction and a second magnetic flow in a second direction;

wherein the first direction is opposite to the second direction;

wherein, in a time versus current diagram, each of the at least two current pulses has a fast raising edge which is essentially vertical and has a slow falling edge;

wherein a sensor electronic is provided;

wherein the sensor electronic implements an automatic slope control;

wherein a wireless sensor power supply and signal read-out is performed; and

wherein a total force measurement performed.